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(54) **HEART TISSUE SURFACE CONTOUR-BASED RADIOSURGICAL TREATMENT PLANNING**

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A61N 5/10	(2006.01)
A61B 19/00	(2006.01)

(52) **U.S. Cl.**
CPC *A61N 5/103* (2013.01); *A61B 19/50* (2013.01); *A61B 2019/504* (2013.01); *A61B 2019/505* (2013.01); *A61B 2019/507* (2013.01)

(58) **Field of Classification Search**
CPC A61B 6/00; A61B 5/05; A61B 19/50; A61N 5/103

USPC 600/1, 427, 443, 439; 378/108, 4–20, 378/64–69, 163–165; 382/103, 128; 128/916; 250/492.1–492.3
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

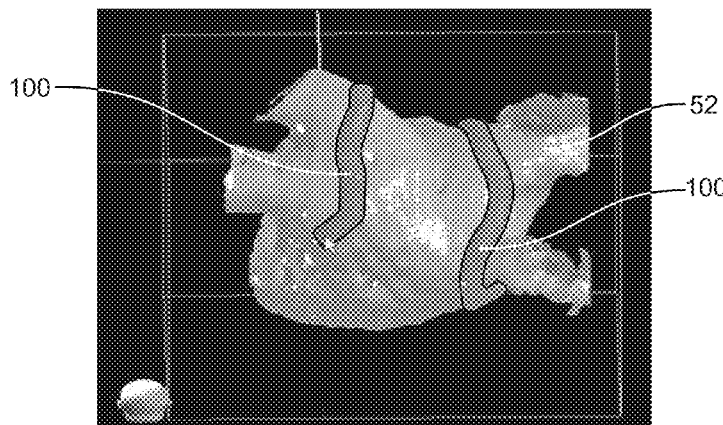|				
5,687,737	A	*	11/1997	Branham et al. 600/523
6,118,847	A		9/2000	Hernandez-Guerra et al.
6,443,894	B1		9/2002	Sumanaweera et al.
6,778,850	B1	*	8/2004	Adler et al. 600/427
6,889,695	B2	*	5/2005	Pankratov et al. 128/898
6,913,603	B2		7/2005	Knopp et al.
7,171,257	B2	*	1/2007	Thomson 600/427
7,756,567	B2	*	7/2010	Kuduvalli et al. 600/427
2004/0131150	A1		7/2004	Pankratov et al.
2006/0009759	A1	*	1/2006	Chrisitian et al. 606/41
2007/0014452	A1		1/2007	Suresh et al.
2007/0032826	A1		2/2007	Schwartz
2008/0317204	A1	*	12/2008	Sumanaweera et al. 378/65
2009/0180589	A1		7/2009	Wang et al.
2010/0183121	A1	*	7/2010	Riker et al. 378/65

* cited by examiner

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(57)   **ABSTRACT**

A system that generates a three-dimensional model of a tissue surface, for example the inner surface of the heart from two-dimensional image data slices. On this surface, one or more pattern lines are drawn, e.g., by a physician using a user interface, to designate desired lesion(s) on the surface. From the pattern lines, a three-dimensional volume for a lesion can be determined using known constraints. Advantageously, the series of boundaries generated by the three-dimensional volume may be projected back onto the individual CT scans, which then may be transferred to a standard radiosurgical planning tool. A dose cloud may also be projected on the model to aid in evaluating a plan.
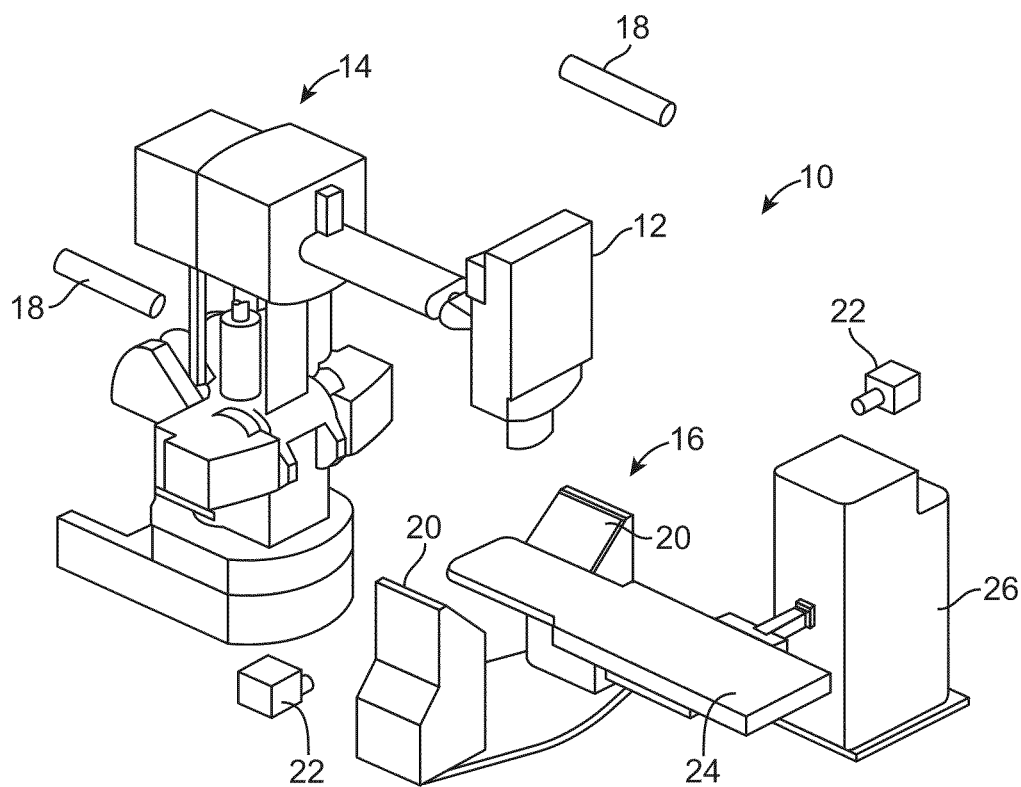
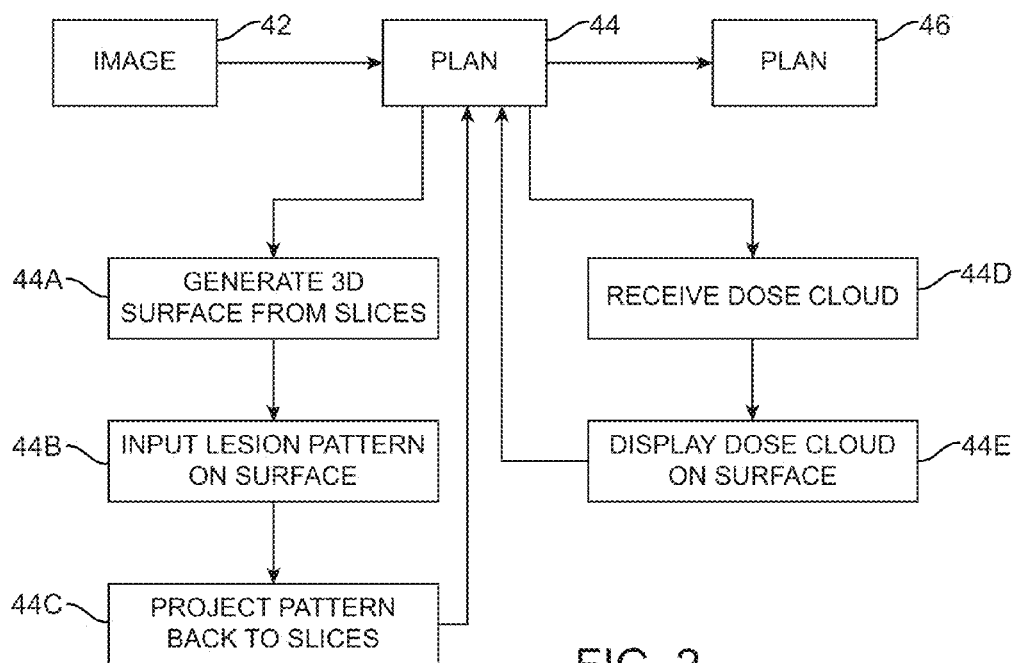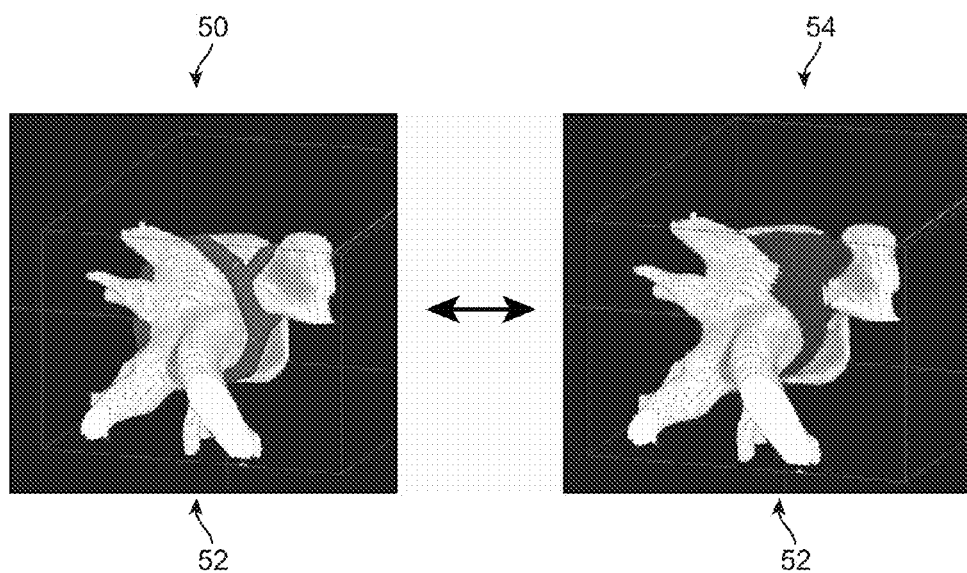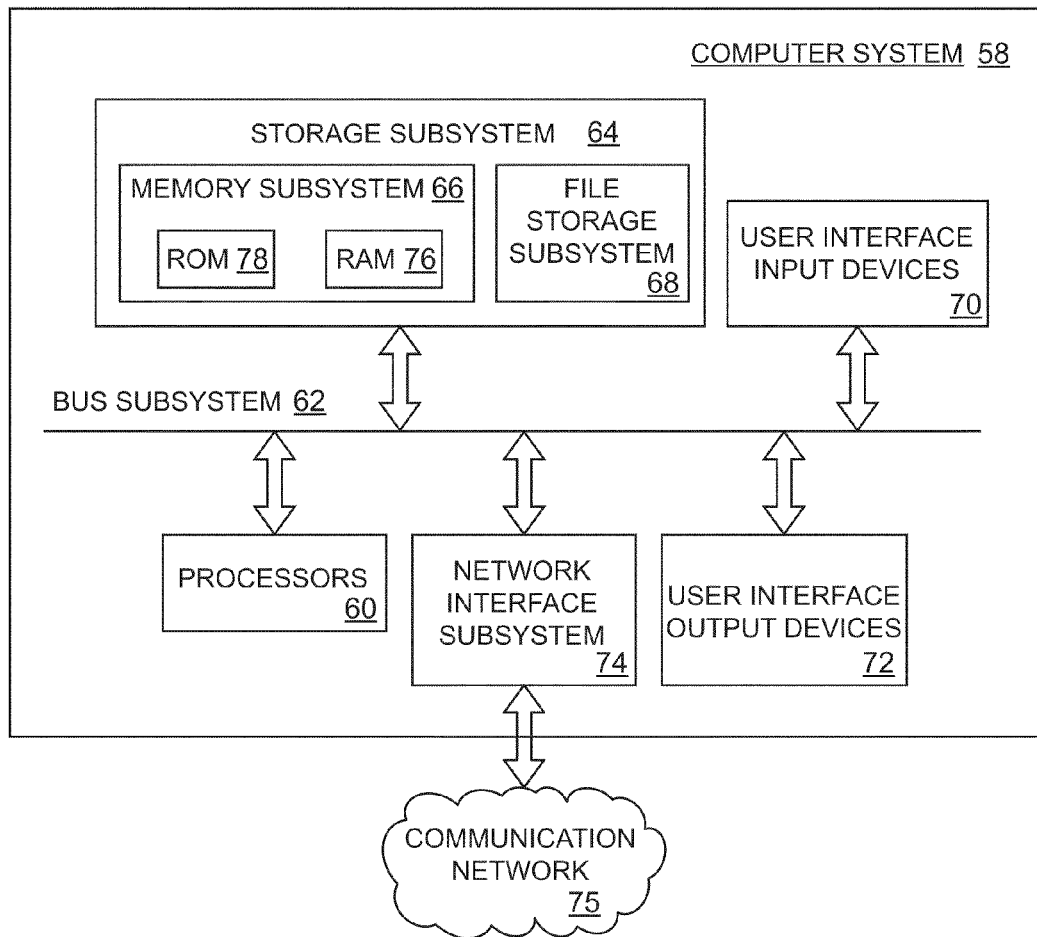**33 Claims, 16 Drawing Sheets**

FIG. 1

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IMAGE  ──42──▶  PLAN  ──44──▶  PLAN  ──46
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44A ─ GENERATE 3D
SURFACE FROM SLICES

44D ─ RECEIVE DOSE CLOUD

44B ─ INPUT LESION PATTERN
ON SURFACE

44E ─ DISPLAY DOSE CLOUD
ON SURFACE

44C ─ PROJECT PATTERN
BACK TO SLICES

FIG. 2

50   54

52   52

FIG. 3

COMPUTER SYSTEM 58

STORAGE SUBSYSTEM   64

MEMORY SUBSYSTEM 66

ROM 78   RAM 76

FILE STORAGE SUBSYSTEM 68

USER INTERFACE INPUT DEVICES 70

BUS SUBSYSTEM 62

PROCESSORS 60

NETWORK INTERFACE SUBSYSTEM 74

USER INTERFACE OUTPUT DEVICES 72

COMMUNICATION NETWORK 75

FIG. 4

80

DIGITAL
DATA
MODULE   82

3D
MODELING
MODULE   84

PLANNING
MODULE   85

TREATMENT
PLANNING
MODULE (E.G.,
MULTIPLAN   88

DOSE CLOUD
MODULE   86

FIG. 5

INPUT CT VOLUME — 602

VOXEL EDITING — 604
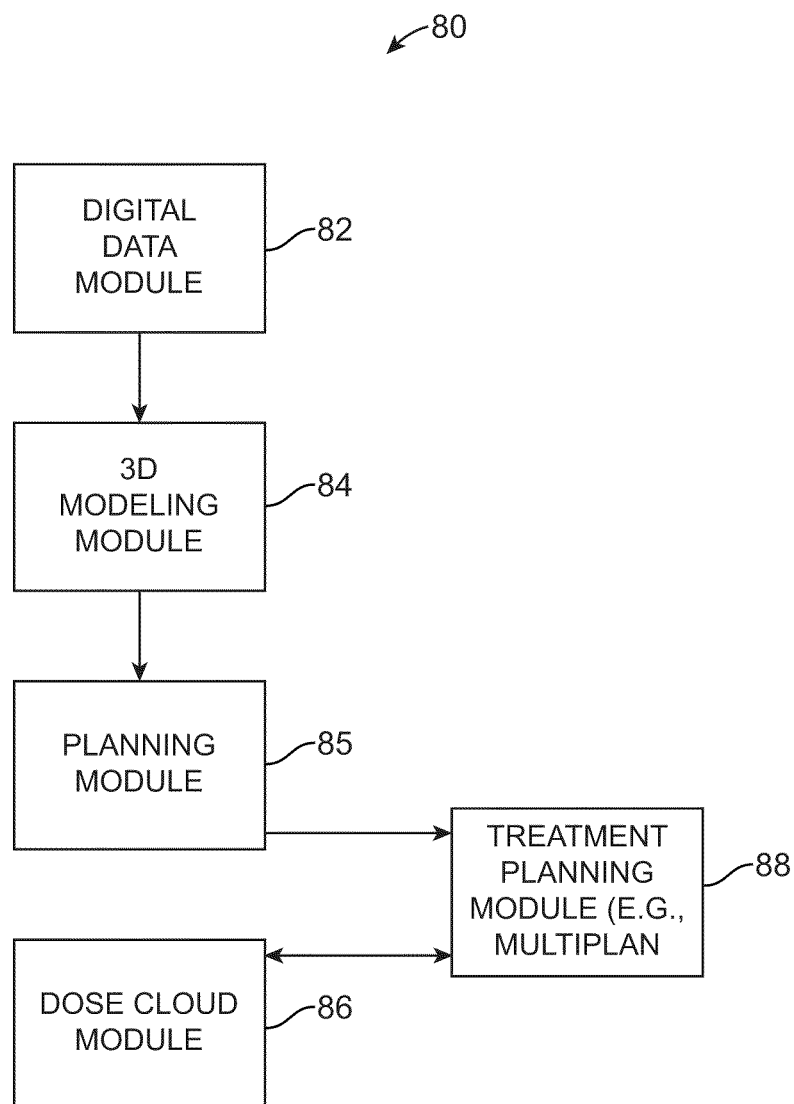
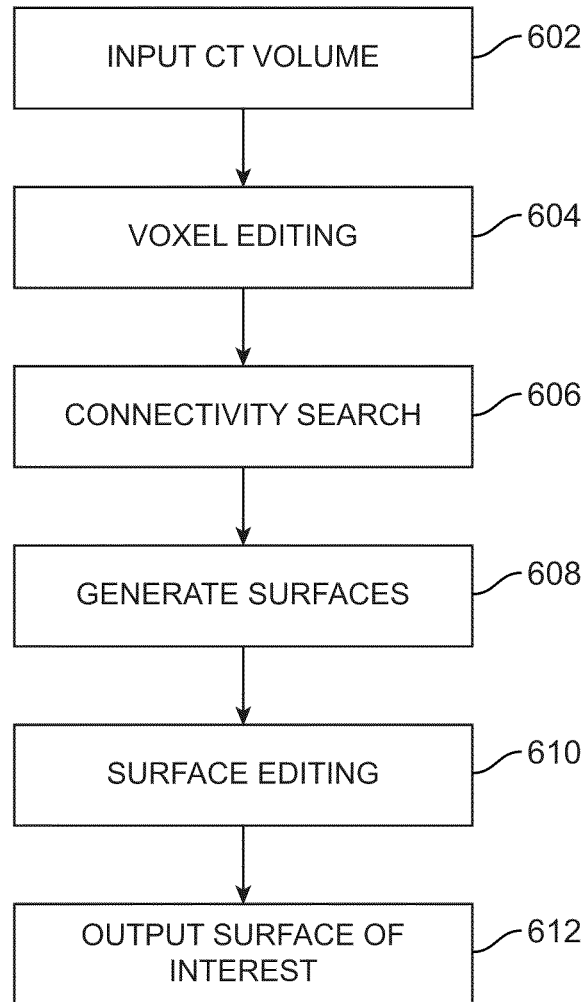CONNECTIVITY SEARCH — 606

GENERATE SURFACES — 608

SURFACE EDITING — 610

OUTPUT SURFACE OF INTEREST — 612

FIG. 6

FIG. 7

FIG. 9

DEFINE ABLATION LINES — 802

SHOW ABLATION LINES IN CARDINAL PLANES — 804

EXPAND ABLATION LINES IN 3D — 806

TESSELATE — 808

CALCULATE CAVITY — 810

GENERATE CONTOURS — 812

OUTPUT TO PLANNING MODULE — 814
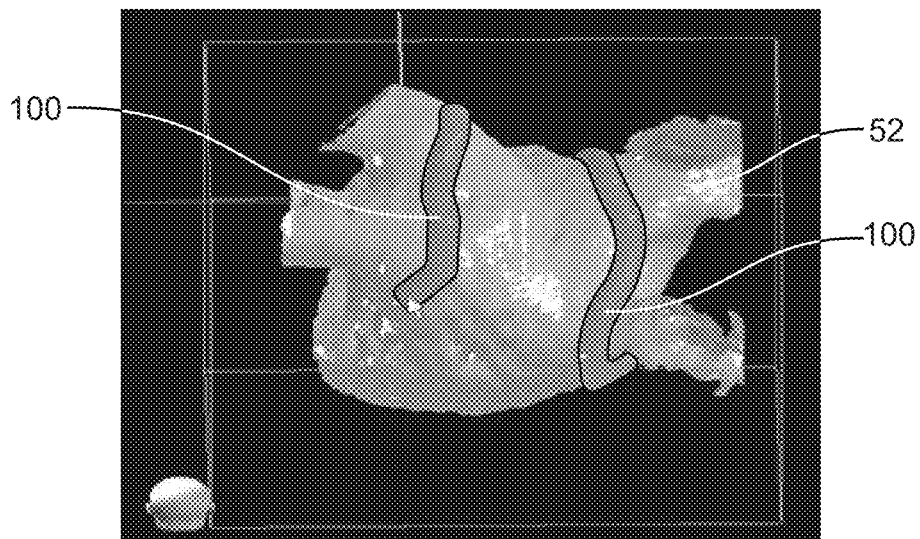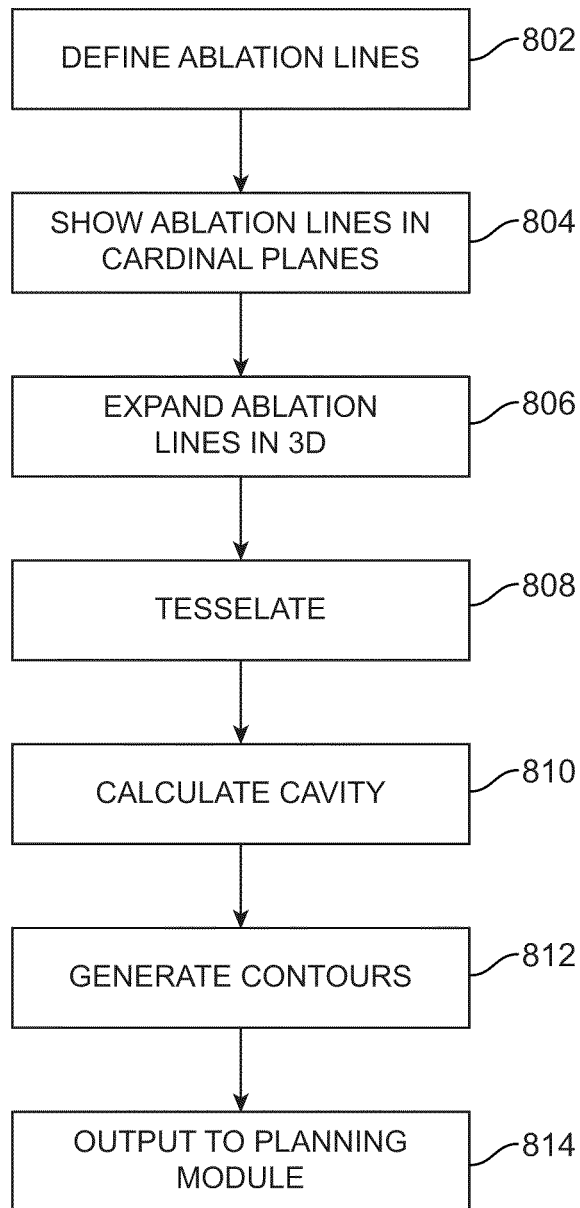
FIG. 8

FIG. 10

FIG. 11

106

106

FIG. 12

108

108

FIG. 13

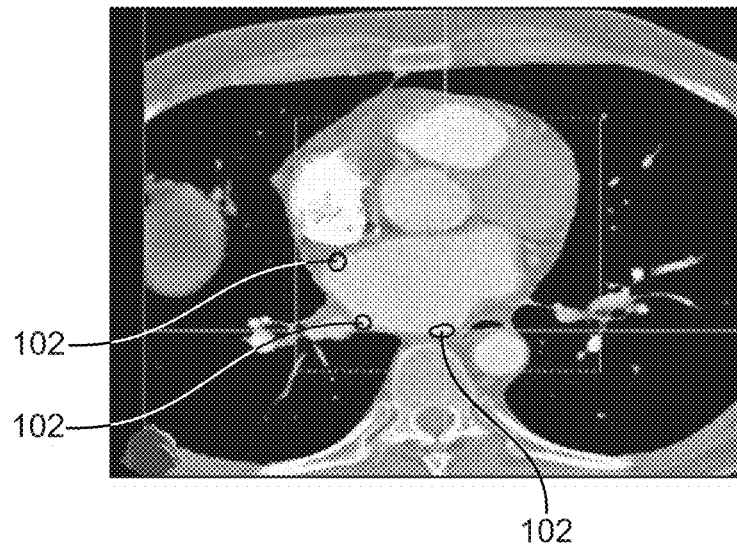FIG. 14

FIG. 15

FIG. 16

FIG. 17

GENERATE DOSE CLOUD —1802

PROJECT DOSE CLOUD ON SURFACE —1804

DISPLAY ABLATION LINES —1806

EVALUATE DOSE CLOUD COVERAGE —1808

FIG. 18

FIG. 19

FIG. 20

CLIP DOSE TO SURFACE ⟋2102

EVALUATE LOOP ⟋2104

DISPLAY ABLATION LINES ⟋2106

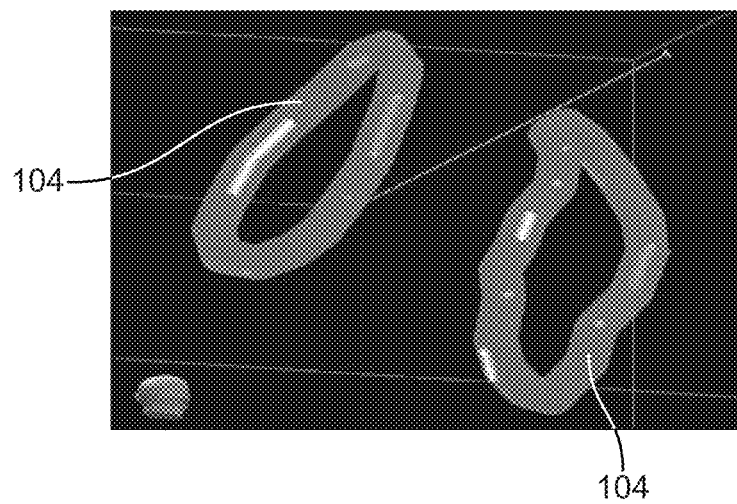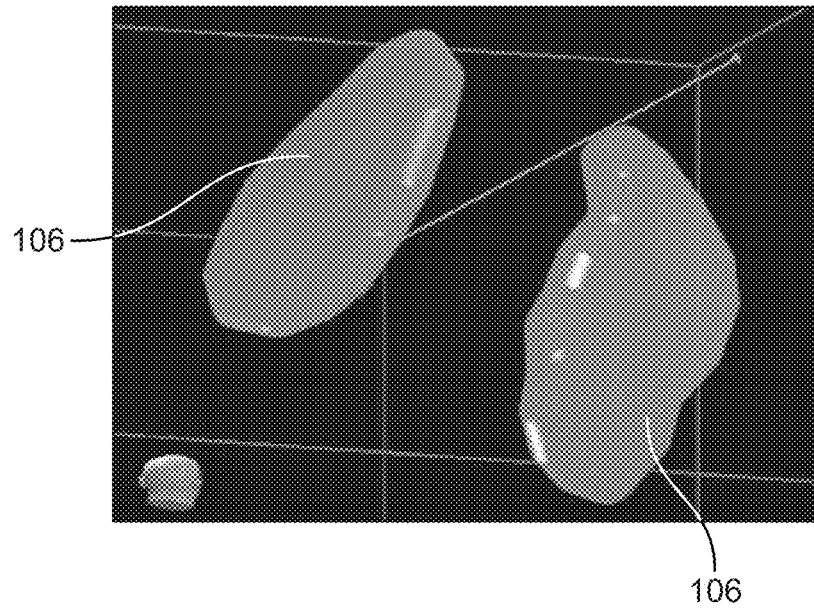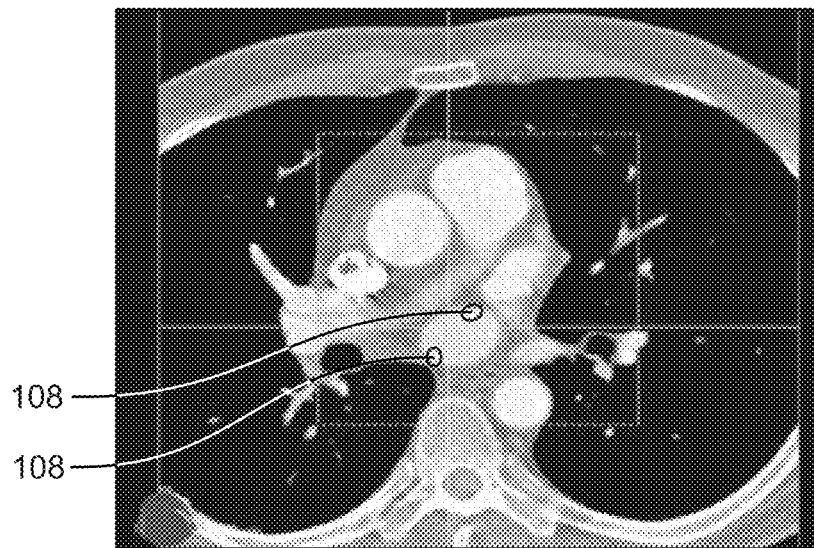CONNECTED? ⟋2108

DISPLAY ABLATION LINES ⟋2110

PROCEED TO TREATMENT ⟋2112
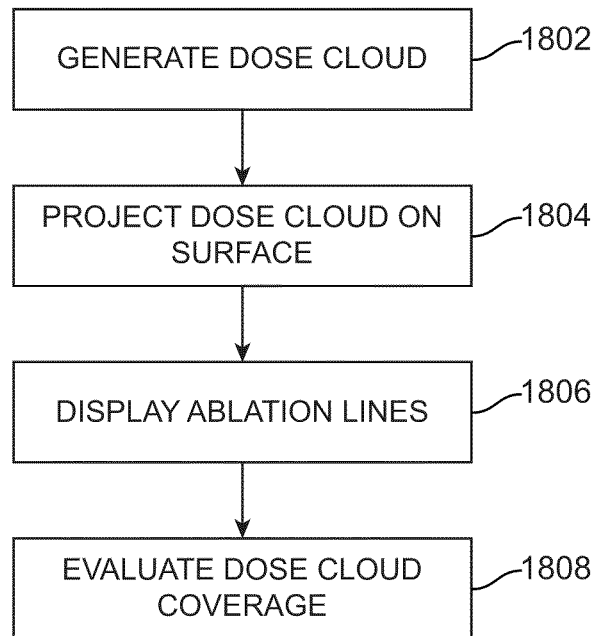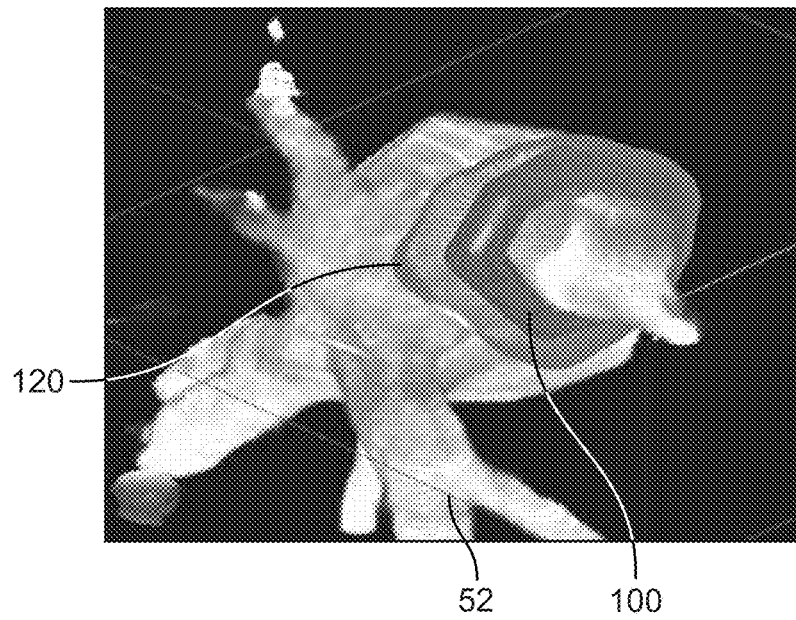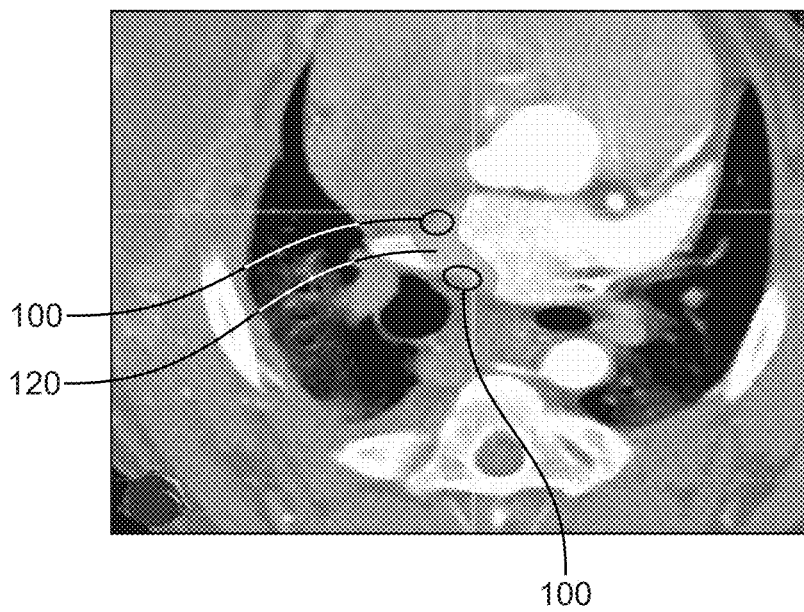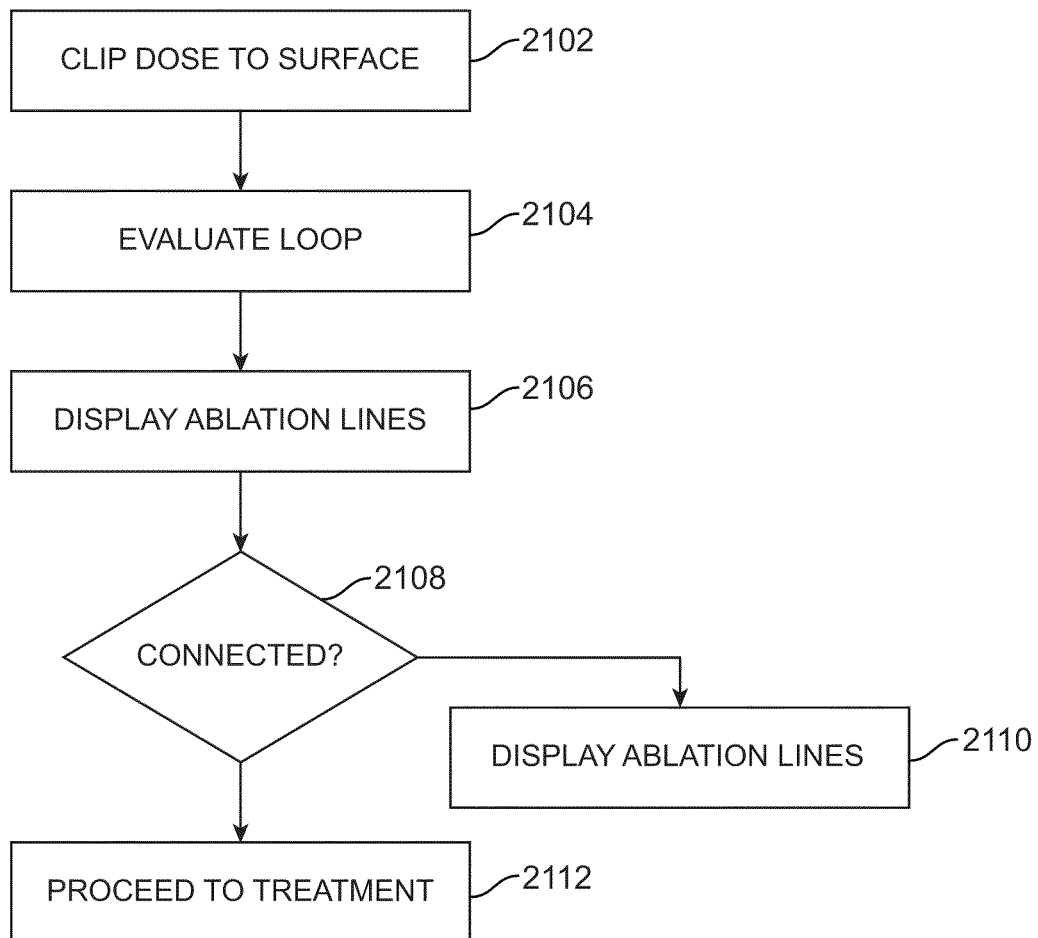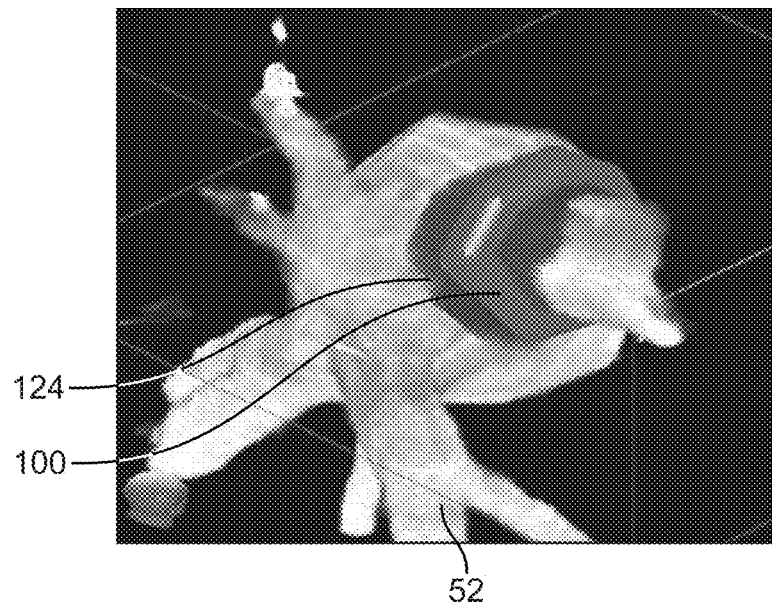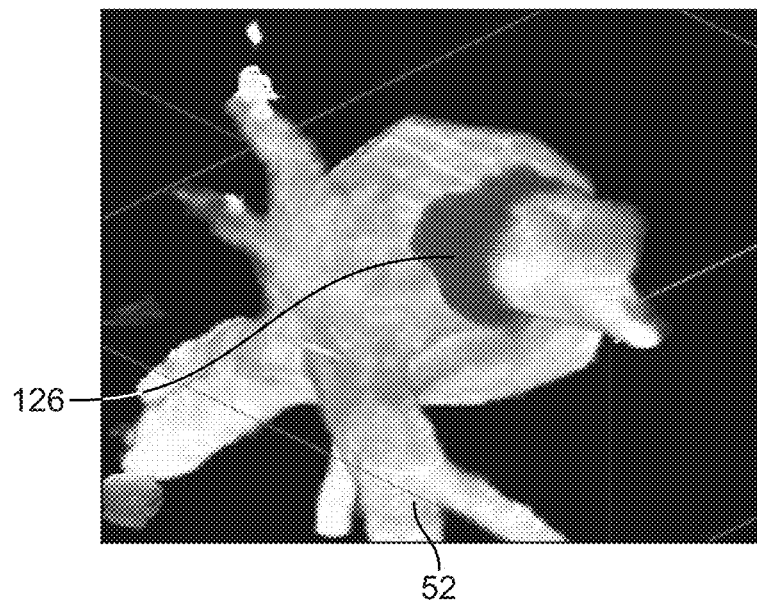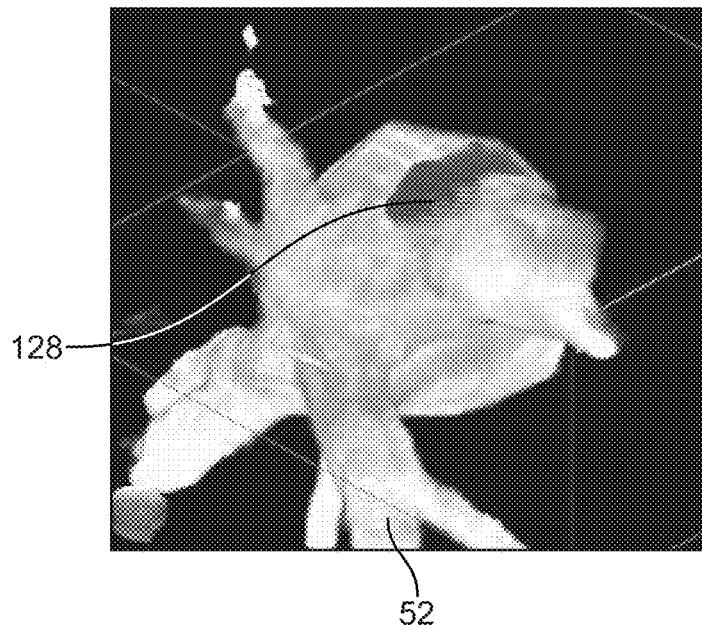
FIG. 21

FIG. 22

FIG. 23

FIG. 24

HEART TISSUE SURFACE CONTOUR-BASED RADIOSURGICAL TREATMENT PLANNING

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/226,613, filed on Jul. 17, 2009, the full disclosure of which is incorporated herein by reference.

BACKGROUND

Tumors and other targets in the head, spine, abdomen, and lungs have been successfully treated using radiosurgery. During radiosurgery, a series of beams of ionizing radiation are often directed from outside a patient so as to converge at a target region, with the radiation beams often comprising MeV X-ray beams fired from different positions and orientations. The beams can be directed through intermediate tissue toward the target tissue so as to alter the biology of a tumor. The beam trajectories help limit the radiation exposure to the intermediate and other collateral tissues, while the cumulative radiation dose at the target can treat the tumor. The CYBERKNIFE radiosurgical system (Accuray Inc.) and the TRILOGY radiosurgical system (Varian Medical Systems) are two known radiosurgical treatment systems.

Modern radiosurgical systems incorporate imaging into the treatment system so as to verify the position of the target tissue and adjust to minor patient movements. Some systems also have an ability to treat tissues that move during respiration, and this feature has significantly broadened the number of patients that can benefit from radiosurgery.

Radiosurgical treatments of other tissues that undergo physiological movements have also been proposed, including the directing of radiation toward selected areas of the heart for treatment of atrial fibrillation and other arrhythmias. During atrial fibrillation, the atria lose their organized pumping action. In a healthy sinus rhythm, the atria contract, the valves open, and blood fills the ventricles or lower chambers. The ventricles then contract to complete an organized cycle of each heart beat. Atrial fibrillation, in contrast, has been characterized as a storm of electrical energy that travels across the atria causing the upper chambers of the heart to quiver or fibrillate. During atrial fibrillation, the blood is not able to empty sufficiently from the atria into the ventricles with each heartbeat. By directing ionizing radiation toward the heart based on appropriate lesion patterns, the resulting scar tissue may prevent recirculating electrical signals and thereby diminish or eliminate the atrial fibrillation.

In standard radiosurgical treatments of tumors and the like, computed tomography (CT) imaging provides a series of planar X-ray scans. For the X-rays adjacent a tumor, the planning physician draws a boundary of the target tissue, with the boundary being drawn on the scan traversing through the tumor and the boundary encompassing the tumor (and typically including some additional offset or margin of treated tissue for safety). As the tumor is typically contained within one organ (but may alternatively extend beyond the organ surface to an adjacent organ) the planned treatment boundary is fairly independent of tissue/tissue interface contours. Hence, the treatment plan is typically drawn up as a series of circles surrounding the tumor on each CT scan in which the tumor is visible.

It is difficult to draw an appropriate arrhythmia lesion treatment plan for forming patterns on conventional planar CT scans using standard radiosurgical planning interfaces. A physician must evaluate the multiple CT scans, and draw

appropriate lines and/or circles representing a treatment plan at each planar slice of the heart. The physician must be able to visualize desired treatment areas from each planer scan. While this appears to be a mere inconvenience, work in connection with the present invention indicates it is surprisingly difficult to efficiently establish an arrhythmia treatment plan using existing radiosurgical treatment planning tools in light of the geometry of the heart.

BRIEF SUMMARY

The following presents a simplified summary of some embodiments of the invention in order to provide a basic understanding of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some embodiments of the invention in a simplified form as a prelude to the more detailed description that is presented later.

In accordance with an embodiment, a system generates a three-dimensional model of a tissue surface of the heart, and specifically of the inner surface (the blood/heart tissue interface). On this surface, one or more pattern lines are drawn, e.g., by a physician using a user interface, to designate desired lesion(s) on the surface for inhibiting contractile pathways. From the pattern lines, a three-dimensional volume for a lesion can be determined using known constraints (such as providing sufficient thickness from the inner heart tissue for the lesion to extend throughout the heart wall, providing sufficient width to prevent propagation of contractions across the lesion, and the like). Advantageously, the series of boundaries generated by the three-dimensional volume may be projected back onto the individual CT scans, which then may be transferred to a standard radiosurgical planning tool.

The radiosurgical planning tool may use existing trajectory calculation routines to generate a radiosurgical plan having several radiosurgical trajectories, or contours. Once the trajectories have been identified to form the desired lesion, a "dosage cloud" can be output to the new planning tool with the display providing an area at the tissue surface (e.g., the blood/heart tissue interface) which will receive sufficient radiation to form a lesion.

To facilitate planning of the radiosurgical treatment, the physician will typically identify locations graphically on the three-dimensional tissue surface, with points and lines snapping to the model of the tissue surface. The output lesion indication may be calculated as a simple isodose contour along the tissue surface.

In an embodiment, a radiosurgical method is provided for treating a patient body having a heart, the heart having a non-tumerous disease. The method includes acquiring three dimensional image data from the heart; generating a three dimensional model of a tissue surface of the heart utilizing the image data; receiving user input on the surface model of a desired ionizing radiation treatment lesion pattern for mitigating the disease; and outputting information regarding a planned lesion pattern relative to the three dimensional image data based upon the desired lesion pattern.

Generating the three dimensional model may include generating a model of the heart based upon a boundary between blood and tissue of the heart. The boundary may be, for example, an inner surface of the heart tissue.

The three dimensional image data from the heart may be a plurality of slices of two dimensional data. Generating the three dimensional model may include generating a model of the heart based upon segments of the boundary between the blood and the heart tissue in each slice of the two dimensional

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data. The three dimensional model may be formed, for example, by stacking or assembling together the segments, and by extending the surface between the segments. In an embodiment, outputting includes projecting the lesion pattern onto each of the plurality of slices of two dimensional data.

A three-dimensional volume for a lesion may be generated based upon the user input, and the information may be generated based upon the three-dimensional volume. The volume may be generated, for example, by expanding the user input to a width that is sufficient to inhibit contractile pathways, expanding the user input to a depth that is sufficient to transmurally penetrate through the tissue of the heart, or expanding the user input to cover an area of tissue of interest at which the treatment is to occur.

In accordance with another embodiment, a radiosurgical method is provided for treating a patient body having a heart, the heart having a non-tumerous disease. The method includes acquiring three dimensional image data from the heart; generating a three dimensional model of a tissue surface of the heart utilizing the image data; receiving user input on the surface model of a desired ionizing radiation treatment lesion pattern for mitigating the disease; and generating a ionizing radiation treatment plan based upon the desired lesion pattern, and projecting a dose cloud relative to the image data based upon the desired treatment plan.

The method may further include snapping the user input for the lesion pattern to the surface of the model. The dose pattern may be evaluated with respect to the user input to determine sufficient treatment which may, for example, involve walking the dose pattern around the surface to confirm that the loop forms a complete circle around the surface. Walking may involve evaluating a thickness of the loop with respect to a threshold.

In accordance with another embodiment, a radiosurgical system is provided for treating a patient body with a heart, the heart having a non-tumerous disease. The system includes an image capture device for acquiring three dimensional planning image data from the heart; and a processor system comprising a modeling module coupled to the image data for generating a surface model of the heart based upon the image data, and an input for identifying a target region of the heart on the surface model, the processor system coupling the input to the modeling module so generate a lesion pattern on the image data in response to the input on the surface model.

In accordance with still another embodiment, a radiosurgical system is provided for treating a patient body with a heart, the heart having a non-tumerous disease. The system includes an image capture device for acquiring three dimensional planning image data from the heart; a radiation source for transmitting a plurality of beams of ionizing radiation from outside the body; and a processor system that includes a planning module having an input for identifying a target region of the heart, the planning module generating a plan of the radiation beams in response to the target region and the planning image data and to project a dose cloud based upon the plan, and a modeling module coupled to the image data for generating a surface model of the heart based upon the image data, the processor system coupling the planning module to the modeling module to project the dose cloud onto the surface model.

For a fuller understanding of the nature and advantages of the present invention, reference should be made to the ensuing detailed description and accompanying drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an exemplary modified stereotactic radiosurgery system that may be utilized with embodiments;

FIG. 2 is a flowchart representing a method of radiosurgical treatment according to embodiments;

FIG. 3 is a representation of a three dimensional model of a heart surface, with a lesion plan added on a left view, and a dose cloud added on a right view, in accordance with embodiments herein;

FIG. 4 is a block diagram of a computer system that may be utilized with embodiments herein;

FIG. 5 schematically illustrates a plurality of modules that may carry out embodiments of the present invention;

FIG. 6 is a flowchart representing a method of generating a three dimensional model of a surface of interest in accordance with an embodiment;

FIG. 7 is a representation of a 3-D model of an inner surface of a heart in accordance with an embodiment;

FIG. 8 is a flow chart representing a method for preparing a treatment plan utilizing the model of the surface generated in FIG. 6 in accordance with an embodiment;

FIG. 9 is a representation of ablation lines 100 being drawn onto the exterior of the surface of FIG. 7 in accordance with an embodiment;

FIG. 10 is a representation of a cardinal plane of the heart for which the surface of FIG. 7 has been generated, showing intersection points of the ablation lines of FIG. 9;

FIG. 11 is a representation of loops generated from the ablation lines of FIG. 9 in accordance with an embodiment;

FIG. 12 is a representation of the loops of FIG. 11 tessellated to form solid volumes in accordance with an embodiment;

FIG. 13 is an axial slice of the heart with a planning target volume projected thereon in accordance with an embodiment;

FIG. 14 is the same axial slice as FIG. 13, but shows a blood target volume projected on the heart in accordance with an embodiment;

FIG. 15 is the same axial slice as FIG. 13, but shows a cavity projected on the heart in accordance with an embodiment;

FIG. 16 is a radiation contour distribution showing contours in accordance with an embodiment;

FIG. 17 is an axial slice of a heart with the contours shown in FIG. 17;

FIG. 18 is a flow chart representing a method of evaluating a dose cloud with respect to the generated surface in accordance with an embodiment;

FIG. 19 shows a dose cloud projected on the generated surface along with ablation lines in accordance with an embodiment;

FIG. 20 is an axial slice of the generated surface of FIG. 19, with the dose cloud and the ablation lines shown thereon;

FIG. 21 is a flow chart representing a method of determining if a dose is sufficient in accordance with an embodiment;

FIG. 22 shows a surface patch indicating dosage coverage on a generated tissue surface in accordance with an embodiment;

FIG. 23 shows a generated surface in which a loop of the dosage surface patch is complete around the generated surface; and

FIG. 24 shows a generated surface in which a loop of the dosage surface patch is not complete around the generated surface.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, various embodiments of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the embodiments. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details. Furthermore, well-known features may be omitted or simplified in order not to obscure the embodiment being described.

Embodiments herein are directed to radiosurgical treatment planning Some described embodiments are directed to radiosurgical planning for treatment of a non-tumor disease of the heart and/or coronary vessels, but the features described herein are not limited to that context.

The radiosurgical treatment planning described herein may take advantage of many components included in or derived from known radiation delivery systems. As an example, an exemplary modified CYBERKNIFE stereotactic radiosurgery system 10 is illustrated in FIG. 1. Radiosurgery system 10 includes a lightweight linear accelerator 12 mounted to a robotic arm 14. An image guidance system 16 includes biplane diagnostic X-ray sources 18 and image detectors 20 so as to enhance registration between robot arm 14 and the target site. As the tissues in the target region may not present a high-contrast image, image guidance system 16 may use image processing techniques to identify the location of one or more surrogate structures, with the surrogates typically including a high-contrast natural tissue structure (such as a bone or the like) or an artificial implanted fiducial marker that moves in correlation with the target tissue. Target tracking may also make use of one or more surface image cameras 22, particularly for identifying movement of the chest wall corresponding to respiration. Cameras 22 may monitor light emitting diodes (LEDs) or other high-contrast fiducial markers visible on the patient's chest. A patient support 24 is movably supported by an alignment arm 26 so as to facilitate bringing the patient (and treatment site) into alignment with robot arm 14.

Referring now to FIG. 2, a relatively simple treatment flowchart 40 can represent a method used before and during radiosurgical treatment according to embodiments of the present invention. The internal tissues are imaged 42 for planning purposes, typically using a remote imaging modality such as a computed tomography (CT), magnetic resonance imaging (MRI), ultrasound imaging, X-ray imaging, optical coherence tomography, a combination of these, or other imaging modalities. Note that the tissue structure which will actually be targeted for radiation remodeling need not necessarily be visible in the image, so long as sufficiently contrasting surrogate structures are visible in the image data to identify the target tissue location. The planning imaging used in many embodiments will include a time sequence of three-dimensional tissue volumes, with the time sequence typically spanning one or more movement cycles (such as a cardiac or heartbeat cycle, a respiration or breathing cycle, and/or the like). In exemplary embodiments, the image data comprises a series of CT slices through the heart so as to provide volumetric or three-dimensional image data. The time series of three-dimensional heart images are preferably acquired at times that are distributed throughout the heartbeat cycle, so that the image planning data effectively comprises a time series of three-dimensional image datasets providing information regarding the motion of cardiac tissues during the heartbeat.

Based on the imaging data obtained from imaging 42, a plan 44 can be prepared for treatment of the tissue at the target site. After completion of plan 44, radiosurgical treatment 46 of the heart may be initiated by positioning the patient on patient support 24, bringing the patient into alignment with robot arm 14, and directing the planned series of radiation beams from the linear accelerator 12 to the target region of the heart.

Embodiments herein are directed to systems and methods that aid in development of the plan 44, which may be used with existing or newly developed imaging 42 and treatment 46. However, one advantage of the plan 44 defined herein is that it may be used with existing imaging, such as the CT imaging described above, and with conventional radiosurgical planning tools, such as the MULTIPLAN planning tool (Accuray, Inc.). Imaging, for example, may take the forms described above, or other forms, but in embodiments utilizes conventional series of slices (e.g., CT slices) through the heart so as to provide volumetric or three-dimensional image data. Treatment 46 may be conventional or modified, and one embodiment is described in concurrently filed U.S. Patent Application No. 61/271,177 entitled, "Heart Treatment Kit, System, and Method for Radiosurgically Alleviating Arrhythmia", the full disclosure of which is incorporated herein by reference.

Treatment plan 44 typically comprises a target region and a series of radiation beams which intersect within the target region. The radiation dose within the target tissue should be at least sufficient to provide the desired lesions. Typically, the radiation dose will be sufficient to ablate tissue, inhibit contractile pathways within the heart, inhibit arrhythmogenesis, and/or the like. Radiation dosages outside the target tissue will preferably decrease with a relatively steep gradient so as to inhibit excessive damage to collateral tissues, with radiation dosages in specified sensitive and/or critical tissue structures often being maintained below a desired maximum threshold to avoid deleterious side effects.

Referring now to FIGS. 2 and 3, broadly described, an exemplary treatment planning module generates 44A a 3D model of a surface 52 (FIG. 3), generally from CT slices, although other imaging data may be used. A user interface allows the system user to input 44B a desired lesion pattern 50 (FIG. 3) with reference to a surface of a tissue, in the example shown in the drawings, the surface 52 of a heart. For treatment of moving tissues of the heart so as to inhibit arrhythmias, the reference heart surface 52 may comprise the blood/tissue interface or the inner surface of one or more heart chambers and adjacent blood vessels. Alternative embodiments may employ an outer surface of the heart as the reference surface, although the inner surface may be more easily identified from the three-dimensional planning image data by introducing imaging contrast agent during the image acquisition step 42. Thus, there is a clear demarcation between the tissue and the blood, allowing for a more precise definition of the surface 52. The lesion pattern 50 is used in part of the plan 44, as described in more detail below.

At 44C, the series of boundaries generated by the lesion pattern 50 may be projected back onto the individual CT scan slices, which then may be transferred to a conventional radiosurgical planning tool. Thus, the input to the conventional radiosurgical tool is generally the same as the input in prior methods (i.e., boundaries defined on individual CT scan slices). However, as described in the background of this disclosure, prior methods required a surgeon to draw on each individual slice. In contrast, methods and systems herein generate the input lesion pattern 50 input onto the solid model of the surface 52.

In an embodiment, as described below, a visualization of a dose cloud **54** (right side of FIG. **3**) may be provided for displaying on the surface **52**. The dose cloud **54** may be received **44**D as an output lesion indication by a conventional radiosurgical tool and, in accordance with embodiments, may be displayed **44**D, for example, as an isodose contour on the surface **52**. As with the lesion pattern **50**, the dose cloud **54** may be used in part of generating or approving the plan **44**, as described in more detail below.

Embodiments herein may utilize computer-implemented methods for generating the surface **52**, indicating a desired lesion pattern **50**, providing the dose cloud **54**, and/or operate the methods or functions of the systems described herein. To this end, FIG. **4** is a simplified block diagram of an exemplary computer system **58** that may be utilized in embodiments described herein. The computer system **58** typically includes at least one processor **60** which communicates with a number of peripheral devices via a bus subsystem **62**. These peripheral devices may include a storage subsystem **64**, comprising a memory subsystem **66** and a file storage subsystem **68**, user interface input devices **70**, user interface output devices **72**, and a network interface subsystem **74**. Network interface subsystem **74** provides an interface to a communication network **75** for communication with other imaging devices, databases, or the like.

The processor **60** performs the operations of the computer system **58** using execution instructions stored in the memory subsystem **66** in conjunction with any data input from an operator. Such data can, for example, be input through user interface input devices **70**, such as the graphical user interface. Thus, processor **60** can include an execution area into which execution instructions are loaded from memory. These execution instructions will then cause processor **60** to send commands to the computer system **58**. Although described as a "processor" in this disclosure, the functions of the processor may be performed by multiple processors in one computer or distributed over several computers.

User interface input devices **70** may include a keyboard, pointing devices such as a mouse, trackball, touch pad, or graphics tablet, a scanner, foot pedals, a joystick, a touchscreen incorporated into the display, audio input devices such as voice recognition systems, microphones, and other types of input devices. In general, use of the term "input device" is intended to include a variety of conventional and proprietary devices and ways to input information into the computer system. Such input devices will often be used to download a computer executable code from a computer network or a tangible storage media embodying steps or programming instructions for any of the methods of the present invention.

User interface output devices **72** may include a display subsystem, a printer, a fax machine, or non-visual displays such as audio output devices. The display subsystem may be a cathode ray tube (CRT), a flat-panel device such as a liquid crystal display (LCD), a projection device, or the like. The display subsystem may also provide non-visual display such as via audio output devices. In general, use of the term "output device" is intended to include a variety of conventional and proprietary devices and ways to output information from the computer system to a user.

Storage subsystem **64** stores the basic programming and data constructs that provide the functionality of the various embodiments. For example, database and modules implementing the functionality of embodiments described herein may be stored in storage subsystem **64**. These software modules are generally executed by processor **60**. In a distributed environment, the software modules may be stored in a memory of a plurality of computer systems and executed by

processors of the plurality of computer systems. Storage subsystem **64** typically comprises memory subsystem **66** and file storage subsystem **68**.

Memory subsystem **66** typically includes a number of memories including a main random access memory (RAM) **76** for storage of instructions and data during program execution and a read only memory (ROM) **78** in which fixed instructions are stored. File storage subsystem **68** provides persistent (non-volatile) storage for program and data files, and may include a hard disk drive, a floppy disk drive along with associated removable media, a Compact Digital Read Only Memory (CD-ROM) drive, an optical drive, DVD, CD-R, CD-RW, or removable media cartridges or disks. One or more of the drives may be located at remote locations on other connected computers at other sites coupled to the computer system. The databases and modules implementing the functionality of the present invention may also be stored by file storage subsystem **68**.

Bus subsystem **62** provides a mechanism for letting the various components and subsystems of the computer system communicate with each other as intended. The various subsystems and components of the computer system need not be at the same physical location but may be distributed at various locations within a distributed network. Although bus subsystem **62** is shown schematically as a single bus, alternate embodiments of the bus subsystem may utilize multiple busses.

The computer system **58** itself can be of varying types including a personal computer, a portable computer, a workstation, a computer terminal, a network computer, a module in a display unit, a mainframe, or any other data processing system. Due to the ever-changing nature of computers and networks, the description of the computer system **58** depicted in FIG. **4** is intended only as a specific example for purposes of illustrating one embodiment of the present invention. Many other configurations of the computer system are possible having more or fewer components than the computer system **58** depicted in FIG. **4**.

FIG. **5** schematically illustrates a plurality of modules **80** that may carry out embodiments of the present invention. The modules **80** may be software modules, hardware modules or a combination thereof. If the modules **80** are software modules, the modules will be embodied on a computer readable medium and processed by the processor **60**.

A digital data module **82** receives CT volume or other diagnostic images and, if not already digitized, creates a digital data file of the images. A 3-D modeling module **84** builds a finite element or solid model of the desired surface from the digital data file. Such 3-D modeling modules are known, and example implementation details are provided below, along with a description of FIG. **6**. However, briefly described, the 3-D modeling module **84** processes the slices of the CT volume and creates a finite element or solid model of the surface of interest, projected as the surface **52** (FIG. **3**). For ease of reference, as used from this point forward, the "surface **52**" refers to the 3-D model of the surface of interest, and in the embodiments described herein, the inner surface of the heart tissue.

The surface **52** may be shown, for example on a display for the computing device **58**, and may be manipulated by a user, for example via the user interface input device **70** so as to see a desired orientation, cross section, or other desired view. Panning and yaw and pitch movement may be provided as well.

A planning module **85** permits a user of the system to generate the lesion pattern **50** (FIG. **3**). The planning module **85** may also project the lesion pattern back onto the CT slices.

A dose cloud module **86** may receive or generate the dose cloud **54**. An example implementation of the dose cloud module **86** is set forth below, for example with the discussions of FIGS. **18** and **21**.

As indicated in FIGS. **3** and **5**, the dose cloud module **86** and the 3-D modeling module **84** may be utilized with a standard treatment planning module **88**. An example of such a treatment planning module is the MULTIPLAN treatment module, although other treatment modules may be used.

FIG. **6** is a flowchart representing a method of generating a surface of interest, e.g., the surface **52**, in accordance with an embodiment. At **602**, the information regarding the CT volume is input, for example via the module **82**. This input may be, for example, a CT volume generate to accentuate the tissue-blood boundary information provided for each CT slice. In the examples described herein, the tissue-blood boundary is inner boundary of the heart, and that boundary is accentuated by, for example, adding contrast agent to the blood. The boundary between the blood (including the added contrast) and the heart tissue in each slice of the CT data can be segmented in one, some, or all of the volumetric datasets associated with the cardiac cycle phases. The segmented regions can be stacked or assembled together to form the surface **52**. The CT data may be edited, for example to limit the left atrium and the pulmonary veins.

At **604** to **610**, examples are provided of smoothing techniques that may be applied between the boundaries of the slices so as to generate a 3-D surface, such as surface **52**. Other smoothing techniques may be used. Smoothing may be performed, for example, via the module **84**.

At **604**, Voxel editing occurs, in which the CT volume is converted to a grid of blocks in three dimensional space. At **606** (optional), connectivity occurs. At **608**, surface generation occurs, for example utilizing the Marching Cubes computer graphics algorithm, which proceeds through the voxels, taking eight neighbor locations at a time (thus forming an imaginary cube), then determining the polygon(s) needed to represent the part of the isosurface that passes through the cube. The individual polygons are then fused into the desired surface.

At **610**, the desired surface is output, for example as shown as the surface **52** in FIG. **7**. For the example herein, the surface **52** represents the inner surface of the heart. The entire process shown in FIG. **6** may be automated using a segmentation scheme.

FIG. **8** is a flow chart representing a method for preparing a treatment plan utilizing the surface **52** generated in FIG. **6**. Beginning at **802**, ablation lines **100** (FIG. **9**) are defined on the surface **52**. For example, the ablation lines **100** may be drawn on or snapped onto the exterior of the surface **52**, for example utilizing the user interface input device **70**. In an example, a physician may click along the surface and the ablation lines **100** may be extend as a straight line between clicks. Smoothing may be enabled. If desired, the surface **52** may be rotated, panned, and zoomed on the screen, or the pitch or yaw may be altered, so as to allow the physician to access a desired view of the surface to properly orient the ablation lines **100**. Such manipulation features are known in existing 3-D modeling and display software.

Applying the ablation lines **100** via the user interface input device **70** allows the planning medical professional to input an appropriate lesion pattern as a series of lines or curves relative to the heart tissue surface **52**. The ablation lines **100** may be applied as a very thin line, or as a thickness that is defined by the system or the user. The thickness of the ablation line may be automatically extracted from the 3D data set as well. In accordance with an embodiment, the ablation lines

are displayed at a width that is sufficient to prevent propagation of contractions across the lesion. Using such a width provides intuitive visual feedback to a user of the system, so that the user may have a more realistic idea of the location and breadth of a lesion pattern.

If desired, at **804** the ablation lines may be shown in one or more cardinal planes. As an example, as is shown in FIG. **10**, a cardinal plane of the heart for which the surface **52** has been generated shows intersection points **102**. The intersection points **102** represent the cross section of the ablation lines **100** at the given cardinal plane. The cardinal planes may be shown either simultaneously on the display, or by toggling between a view of the surface **52** and the cardinal plane. The cardinal planes may represent, for example, data from a single CT slice.

At **806**, the ablation lines **100** are expanded to volumes so as to provide the desired therapeutic benefit, and may be visualized on the display in three dimensions. **804** may occur after **806** and indeed, unless stated otherwise herein, the acts set forth in the flowcharts of this disclosure are not limited to the order in which they are presented. To visualize the volume in three dimensions, the ablation lines **100** may be given a three-dimensional thickness, such as by generating loops **104** (FIG. **11**). In accordance with an embodiment, since the surface **52** represents an inner surface of the heart, the loops **104** are generated by generating loops having a radius around the ablation lines **100**, with the radius being approximately equal to, or slightly more than, the thickness of the tissue to be treated. Thus, the thickness may be sufficient from the inner heart surface for the lesion to extend throughout the heart wall. The radius may be applied around the ablation lines, or separate width and length radii may be used. The width may be selected, for example, to be sufficient to prevent propagation of contractions across the lesion. In an example, the loops **104** may be generated utilizing a radius of two millimeters, but other radii may be used and, as described above, a loop does not necessarily need to be uniform in width and thickness. The thickness of the ablation line may be automatically extracted from the three dimensional data set as well

In an embodiment, the loops **104** enclose the pulmonary vein ostia (PVOS) and define a planning target volume (PTV) for treatment planning purposes. The PTV represents the area of tissue of interest at which treatment is desirably to occur. In the example of the heart, the PTV is preferably the tissue of the heart, from the outer surface of the heart to an inner surface, and a width sufficient to inhibiting contractile pathways.

At **808**, the non-planar polygon defined by each loop **104** is tessellated to form solid volumes **106** (FIG. **12**). Tessellation may, for example, result in the non-planar polygons being tessellated into triangles, and dilated to the thickness of the ablation line. The solid volumes **106** represent a blood target volume (BTV).

FIG. **13** is an axial slice of the heart showing the PTV **108**. The PTV **108** in FIG. **13** is shown as two circles, which represent a cross section of the loops **104** formed by the PTV. FIG. **14** is the same axial slice as FIG. **13**, but shows the BTV **110**. The BTV **110** is represented by the solid volume **106**, and includes the desired area of treatment (i.e., the PTV), plus the area in between, which is presumably blood and, in FIG. **14** is represented by an elongated, irregular oval. In general, the blood may be irradiated during treatment without harm, and the treatment plan may be prepared with the assumption that the BTV will be radiated at all locations to an extent sufficient to treat the PTV. At **810**, a cavity **112** (shown in axial

slice in FIG. **15**) is calculated by subtracting the PTV from the BTV. The cavity **112** represents the area of the BTV presumed to be blood.

At **812**, the PTV and BTV are scan converted to generate contours in each of the cardinal planes. Existing radiosurgical radiation beam calculating modules may be used to determine the resulting radiation contour distribution. Existing radiosurgical planning approaches to identification of radiation sensitive structures may be implemented. The input to such existing calculating modules may require input via slices, such as conventional CT slices. Thus, if such calculating modules are used, the CT slices are utilized to generate the solid volume (FIG. **6**), the plan is formed on the solid volume (FIG. **8**), and then the plan at each slice is provided back to the calculating module to generate the contours. Thus, the output **814** may be an output relative to each of the original CT slices. An example of generated contours **114** is shown in FIG. **16**. An example of an axial slice of the contours **114** is shown in FIG. **17**.

Alternatively, the ablation lines **100** may be defined using a cardiac and/or respiratory gated 4DCT data set. Suppose there N (typically N=10) volumes of CT data acquired over time. A heart-wall surface (e.g., the surface **52**) will be constructed from each CT volume, resulting in N such surfaces. Using each surface, a set of ablation lines will be defined by the user, resulting in N such ablation lines. This time-varying ablation lines and the time-varying CT data will then be imported to a treatment planning station line treatment planning module, e.g., MULTIPLAN, for generating a treatment plan. Alternatively, one ablation line set, whose volume will include the volumes from all individual ablation lines, can be generated and used for planning.

In accordance with an embodiment, placement of the ablation lines on a surface may be partially or fully automated. A template of possible ablation lines may be provided to the user, and the user may then drag and drop the selected template at a proper location on the surface. The user may modify the ablation line locally by moving it around on the surface. The thickness may also be changed.

The contours **114** may be saved, for example, as DICOM RTSS (Radiation Therapy Structure Sets) files. The planner to which they are output may be, for example, MULTIPLAN. In an embodiment, optimization in MULTIPLAN is done using the BTV, while evaluation is done using PTV. The volume of the BTV in general is significantly larger than the PTV. The BTV is also a shape topologically closer to a sphere than the PTV, which is topologically closer to a hole, which is formed by the radiation pattern. Because of these reasons, implementing a treatment plan based on the BTV is preferred. Optimizing the plan based on the PTV is preferred because focus is on the actual area in which treatment is desired.

In another embodiment, instead of transmitting the ablation lines as 2D contours in cardinal planes or oblique planes to a planning module, the ablation lines may be transmitted as 3D shapes to the planning module.

Along with inputting a desired lesion pattern, as schematically illustrated on the right side of FIG. **5**, the planning module and user interface will preferably output an estimate of the actual radiation exposure along the surface of a heart, preferably in the form of an estimated heart surface lesion **54**. Estimated lesion **54** may represent the portion of heart tissue surface **52** which receives a radiation dose above a necrotic threshold, optionally based on radiation beams and radiation dose output from an existing radiosurgical treatment planner. Alternative patterns may represent an estimate of tissue which will receive a sufficient dose of radiation for therapeutic remodeling so as to inhibit the arrhythmia. The user may

interactively develop the plan based on iterative input into and output from the planning treatment module **88**.

Ideally, the dose cloud should correspond to the ablation lines. Embodiments herein strive to create a plan that provides treatment as an ring of fibrotic tissue corresponding to ablation lines.

FIG. **18** is a flow chart representing a method of evaluating a dose cloud with respect to the generated surface **52** in accordance with an embodiment. At **1802**, the dose cloud is generated and is overlaid over the surface **52** at **1804**. If desired, the ablation lines **100** are displayed on the surface **52** at **1806**.

As shown in FIG. **19**, displaying the ablation lines **100** and a dose cloud **120** relative to the surface **52** allows a visual inspection of whether the dose cloud is covering the target intended by the physician. To this end, at **1808**, the physician may visually evaluate whether the dose cloud is covering the target. As can be seen in FIG. **19**, for at least the view shown in the drawing, the dose cloud **120** fully covers the ablation lines **100**. Rotation, panning, or zooming of the surface, or adjustment of the pitch and/or yaw, may be required for a full inspection of dosage coverage.

The dose cloud **120** may represent, for example, all dose values that are greater than a particular threshold or, as an alternative, dose values lying in a range between a minimum and a maximum. If desired, as shown in FIG. **20**, an axial slice of each cardinal plane may be provided, with the dose cloud **120** and the ablation lines **100** shown thereon. This representation permits a physician to look at each slice to ensure that the dose is covering (e.g., surrounding) the target adequately.

FIG. **21** is a flow chart representing a method of determining if a dose is sufficient in accordance with an alternate embodiment. The method in FIG. **21** involves clipping a dose cloud to the surface **52**, and may be used in addition to, or instead of the visual inspection described above, where the dose cloud is represented more as a contour. At **2102**, the region corresponding to the acceptable dose value is clipped to the surface **52**, for example as a different color than the ablation lines **100**. The dose values may be represented in isodose fashion, with different doses being displayed in different ways, for example as different colors. Alternatively, as in the previous embodiment, all doses exceeding a value or falling in a range may be displayed.

By clipping the dose value to a surface, the dose is presented as a curved surface patch **124** (FIG. **22**) on the surface **52**. If the dosage values are selected correctly, fibrosis should take place on the surface patch **124**. A physician may visually evaluate the surface patch **124** with respect to the ablation lines **100** to determine whether sufficient dosage is provided. For example, the surface patch may be evaluated to determine whether it is wide enough to inhibit contractile pathways in the tissues being treated.

In addition, with or without the ablation lines **100** removed, the physician may evaluate the surface patch **124** to determine whether the surface patch forms a continuous loop at **2104**. If there are any breaks in the loop, inhibiting contractile pathways may not be provided by the radiological treatment. To this end, at **2106**, the physician evaluates whether the surface patch **124** is connected around the surface **52**, such that a continuous loop is formed. If not, an error may be generated at **2108**, either by software or a recognition by the user, causing the physician to construct a new plan or causing the computer system **58** to generate an error message, or to be handled in another manner. If the loop is connected, then the physician may proceed to treatment at **2110**.

FIG. **23** shows the surface **52** in which a complete loop **126** around the surface **52** is formed by the surface patch **124**. The

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physician and/or the computer system **58** may rotate and otherwise manipulate the surface **52** so that the physician may fully inspect the loop **126**. In an alternate embodiment, software may walk across the loop **126** to confirm that the loop returns to a starting position to make sure that the fibrotic region is connected. This same software or visual inspection may be used to determine whether the loop is sufficiently wide around the entire loop **126**. For example, the software may crawl around the surface **52**, and evaluate a pixel width of the loop **126**. If the pixel width falls below a threshold, an error may be generated.

Any effects of possible misalignment errors (x, y, z translation and roll, pitch, yaw, rotation errors) during treatment may be evaluated with this system. The surface or the CT data set may be translated and rotated in relation to the dose cloud to understand the effect of any misalignment on the continuity of the fibrotic loop at the PVOS. Alternatively the dose cloud may be translated or rotated in relation to the surface or the CT data set.

FIG. **24** shows a partial loop **128** that does not extend entirely around the surface **52**. In this example, the physician or the software may require that a new treatment plan be prepared or may otherwise generate an error (e.g., at **2108**).

After the contours are approved, the plan **44** is complete, and may be implemented. Radiosurgical treatment of the heart **46** may be initiated, for example, by positioning the patient on patient support **24**, bringing the patient into alignment with robot arm **14**, and directing the planned series of radiation beams from the linear accelerator **12** to the target region of the heart.

Other variations are within the spirit of the present invention. Thus, while the invention is susceptible to various modifications and alternative constructions, certain illustrated embodiments thereof are shown in the drawings and have been described above in detail. It should be understood, however, that there is no intention to limit the invention to the specific form or forms disclosed, but on the contrary, the intention is to cover all modifications, alternative constructions, and equivalents falling within the spirit and scope of the invention, as defined in the appended claims.

The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. The term "connected" is to be construed as partly or wholly contained within, attached to, or joined together, even if there is something intervening. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate embodiments of the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

What is claimed is:

1. A radiosurgical method for treating a patient body having a heart, the heart having a non-tumorous disease and a blood/tissue boundary surface extending along a boundary between the heart and blood disposed therein, the method comprising:

   acquiring three dimensional image data from the heart;

   generating a three dimensional blood/tissue surface model of the blood/tissue boundary surface of the heart utilizing the image data;

   displaying a rendering of the generated three dimensional blood/tissue surface model on a display of a user interface;

   receiving user input, through a user input of the user interface and with reference to the displayed rendering of the three dimensional blood/tissue surface model, of an ionizing radiation treatment lesion pattern for mitigating the disease;

   snapping the lesion pattern inputted with reference to the displayed rendering of the three dimensional blood/tissue surface model to the three dimensional blood/tissue surface model to provide a desired lesion pattern; and

   outputting information regarding a planned lesion pattern relative to the three dimensional image data based upon the desired lesion pattern; and

   treating the heart of the patient with the planned lesion pattern.

2. The method of claim **1**, wherein the three dimensional image data from the heart comprises a plurality of slices of two dimensional data, and wherein generating the three dimensional blood/tissue surface model is based upon segments of the blood/tissue boundary in each slice of the two dimensional data.

3. The method of claim **2**, wherein the three dimensional blood/tissue surface model is formed by stacking or assembling together the segments, and by extending the blood/tissue boundary surface between the segments.

4. The method of claim **2**, wherein outputting comprises projecting the desired lesion pattern onto each of the plurality of slices of two dimensional data.

5. The method of claim **1**, wherein the three dimensional image data from the heart comprises a plurality of slices of two dimensional data, and wherein outputting comprises projecting the desired lesion pattern onto each of the plurality of slices of two dimensional data.

6. The method of claim **1**, further comprising generating a three-dimensional volume for a lesion based upon the user input, and generating the information based upon the three-dimensional volume.

7. The method of claim **6**, wherein generating the volume comprises expanding the user input to a width that is sufficient to inhibit contractile pathways.

8. The method of claim **6**, wherein generating the volume comprises expanding the user input to a depth that is sufficient to transmurally penetrate through the tissue of the heart.

9. The method of claim **6**, wherein generating the volume comprises expanding the user input to cover an area of tissue of interest at which a treatment is to occur.

10. The method of claim **1**, further comprising generating an ionizing radiation treatment plan based upon the information, and projecting a dose cloud to the blood/tissue surface model based upon the treatment plan.

11. The method of claim **10**, further comprising evaluating the dose cloud with respect to the user input to determine sufficient treatment.

12. The method of claim **11**, wherein evaluating comprises walking the dose cloud around the surface of the blood/tissue surface model to confirm that a loop forms an enclosed perimeter around the surface of the blood/tissue surface model.

13. The method of claim **12**, wherein walking comprises evaluating a thickness of the loop with respect to a threshold.

14. A radiosurgical method for treating a patient body having a heart, the heart having a non-tumorous disease and a blood/tissue boundary surface extending along a boundary between the heart and blood disposed therein, the method comprising:

    acquiring three dimensional image data from the heart;

    generating a three dimensional blood/tissue surface model of the blood/tissue boundary surface of the heart utilizing the image data;

    providing a user interface comprising a display and a user input;

    displaying a rendering of the generated three dimensional blood/tissue surface model on the display of the user interface;

    manipulating the three dimensional blood/tissue surface model with reference to the rendering of the generated three dimensional blood/tissue surface model to generate a manipulated rendering;

    receiving user input through the user interface and with reference to the displayed manipulated rendering of the three dimensional blood/tissue surface model of an ionizing radiation treatment lesion pattern for mitigating the disease;

    wherein receiving user input comprises:

        snapping an initial user input of the ionizing radiation treatment lesion pattern to the three dimensional blood/tissue surface model;

        snapping a subsequent user input of the ionizing radiation treatment lesion pattern to the three dimensional blood/tissue surface model;

        extending an ablation line along the three dimensional blood/tissue surface model from the initial user input of the ionizing radiation treatment lesion pattern to the subsequent user input of the ionizing radiation treatment lesion pattern to provide a desired treatment pattern; and

    displaying a rendering of the ablation line superimposed on the three dimensional blood/tissue surface model;

    generating an ionizing radiation treatment plan based upon the desired lesion pattern, and projecting a dose cloud relative to the image data based upon the desired treatment plan;

    treating the heart of the patient with the generated ionizing radiation treatment plan.

15. The method of claim **14**, further comprising evaluating the dose cloud with respect to the user input to determine sufficient treatment.

16. The method of claim **15**, wherein evaluating comprises walking the dose cloud around the surface of the blood/tissue surface model to confirm that a loop forms a complete circle around the surface of the blood/tissue surface model.

17. The method of claim **16**, wherein walking comprises evaluating a thickness of the loop with respect to a threshold.

18. A radiosurgical system for treating a patient body with a heart, the heart having a non-tumorous disease, the system comprising:

    an image capture device for acquiring three dimensional planning image data from the heart; and

    a processor system comprising a modeling module coupled to the image data for generating a three dimensional tissue surface model of the heart in three dimensional space based upon the image data, and

    an input for receiving user input identifying a target region of the heart in three dimensional space on the surface model in three dimensional space, the processor system coupling the input to the modeling module to generate a lesion pattern in three dimensional space on the image data in response to a received user input on the surface model in three dimensional space; and

    wherein the processor system is configured to snap the user input in three dimensional space to a surface of the tissue surface model in three dimensional space to facilitate treatment planning; and

    wherein the processor system is configured to treat the heart of the patient with the generated lesion pattern.

19. The apparatus of claim **18**, wherein the modeling module is configured to generate the three dimensional tissue surface model of the heart based upon a boundary between blood and tissue of the heart.

20. The apparatus of claim **19**, wherein the boundary comprises an inner surface of the heart tissue.

21. The apparatus of claim **19**, wherein the three dimensional planning image data from the heart comprises a plurality of slices of two dimensional data, and wherein the modeling module is configured to generate the three dimensional model of the heart based upon segments of the boundary between the blood and the heart tissue in each slice of the two dimensional data.

22. The apparatus of claim **21**, wherein the modeling module is configured to generate the three dimensional model of the heart by stacking or assembling together the segments, and by extending the surface between the segments.

23. The apparatus of claim **21**, wherein the processing system is configured so that generating comprises projecting the lesion pattern onto each of the plurality of slices of two dimensional data.

24. The apparatus of claim **18**, wherein the three dimensional image data from the heart comprises a plurality of slices of two dimensional data, and wherein the processing system is configured so that generating comprises projecting the lesion pattern onto each of the plurality of slices of two dimensional data.

25. The apparatus of claim **18**, wherein the processing system is configured to generate a three-dimensional volume for a lesion based upon the input.

26. The apparatus of claim **25**, wherein generating the volume comprises expanding the user input to a width that is sufficient to inhibit contractile pathways.

27. The apparatus of claim **25**, wherein generating the volume comprises expanding the user input to a depth that is sufficient to transmurally penetrate through the tissue of the heart.

28. The apparatus of claim **25**, wherein generating the volume comprises expanding the user input to cover an area of tissue of interest at which a treatment is to occur.

29. A radiosurgical system for treating a patient body with a heart, the heart having a non-tumorous disease and a tissue boundary surface, the system comprising:

an image capture device for acquiring three dimensional planning image data from the heart;

a radiation source for transmitting a plurality of beams of ionizing radiation from outside the body; and

a processor system comprising:

a planning module having an input for receiving a user input identifying a desired three dimensional lesion pattern of a target region of the heart, the planning module configured to project the desired three dimensional lesion pattern in three dimensional space to generate two dimensional contours in each of a plurality of two dimensional data slices, the planning module configured to generate a plan of the radiation beams based on the two dimensional contours such that the radiation beams intersect within the heart to

form a three dimensional lesion corresponding to the three dimensional lesion pattern, and to project a three dimensional dose cloud based upon the plan, and

a modeling module coupled to the image data for generating a three dimensional surface model of the tissue boundary surface of the heart based upon the image data,

the processor system coupling the planning module to the modeling module to project the three dimensional dose cloud onto the three dimensional surface model;

wherein the processor system is configured to treat the heart of the patient with the generated plan of the radiation beams.

30. The apparatus of claim **29**, wherein the processor system is configured to snap the user input for the lesion pattern to the surface of the model.

31. The apparatus of claim **30**, wherein the processor system is configured to evaluate the dose pattern with respect to the user input to determine sufficient treatment.

32. The apparatus of claim **31**, wherein evaluating comprises walking the dose pattern around the surface to confirm that the loop forms a complete circle around the surface.

33. The apparatus of claim **32**, wherein walking comprises evaluating a thickness of the loop with respect to a threshold.

*   *   *   *   *